

SPEC_{inc}

A Comparison of Microphysical Properties of Wave, Cirrus and Anvil Clouds



**NASA CRYSTAL-FACE
Workshop – Salt Lake City
24 - 28 February 2003**

OUTLINE

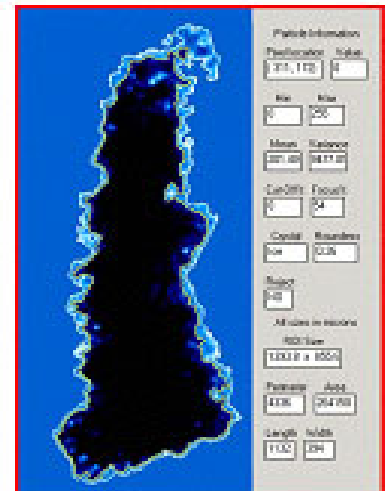
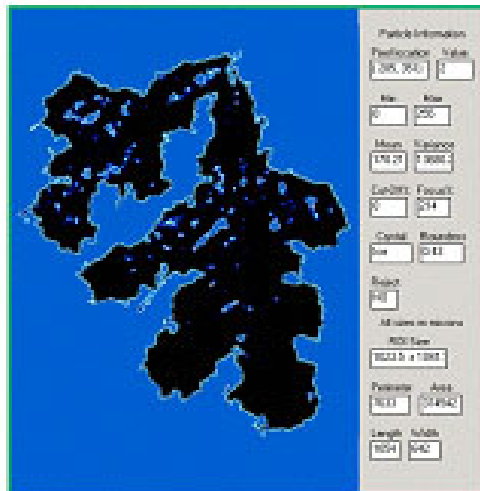
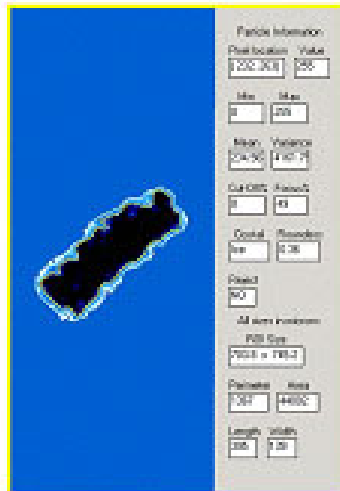
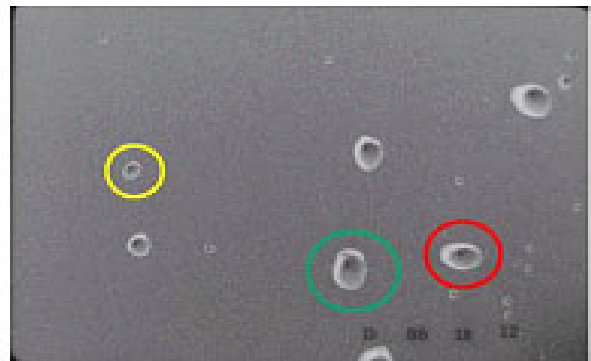
- **WAVE CLOUDS:** Composite of 12 SPEC Learjet flights over the Front Range of the Rockies
- **CIRRUS CLOUDS:** Composite of 10 SPEC Learjet flights in Utah, Colorado and Oklahoma
- **ANVIL CLOUDS:** Examples of Data:
 - SPEC Learjet in Colorado
 - UND Citation near Cape Kennedy (ABFM Project)
 - ARA Egrett - Darwin, Australia
 - WB-57 and UND Citation (CRYTSTAL- FACE)

IWC Improvement

PHOTOGRAPHED
CRYSTALS



EQUIVALENT
MELTED DROPS



More Parameters are used in the New Image Processing Technique

OLD TECHNIQUE

(Mitchell et al. 1990)

$$\text{Mass} = \alpha X^{\beta}$$

where: $X = L = \text{Length}$



NEW TECHNIQUE

(SPEC 2002)

$$\text{Mass} = \alpha X^{\beta}$$

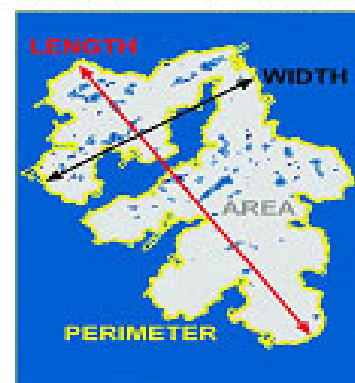
where: $X = A \times W \times 2(L + W)/P$

$L = \text{Length}$

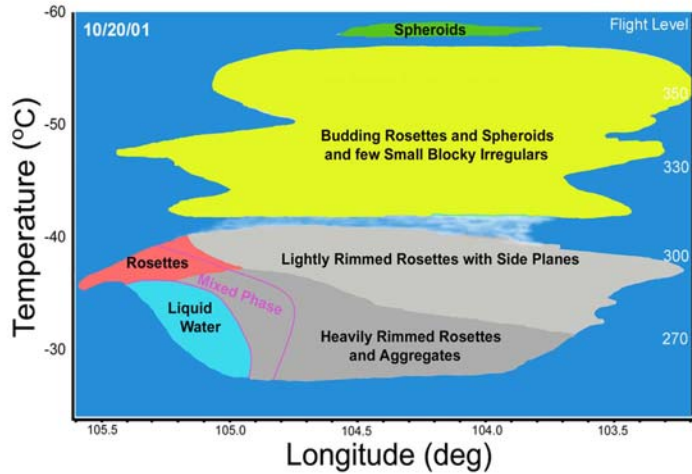
$W = \text{Width}$

$A = \text{Area}$

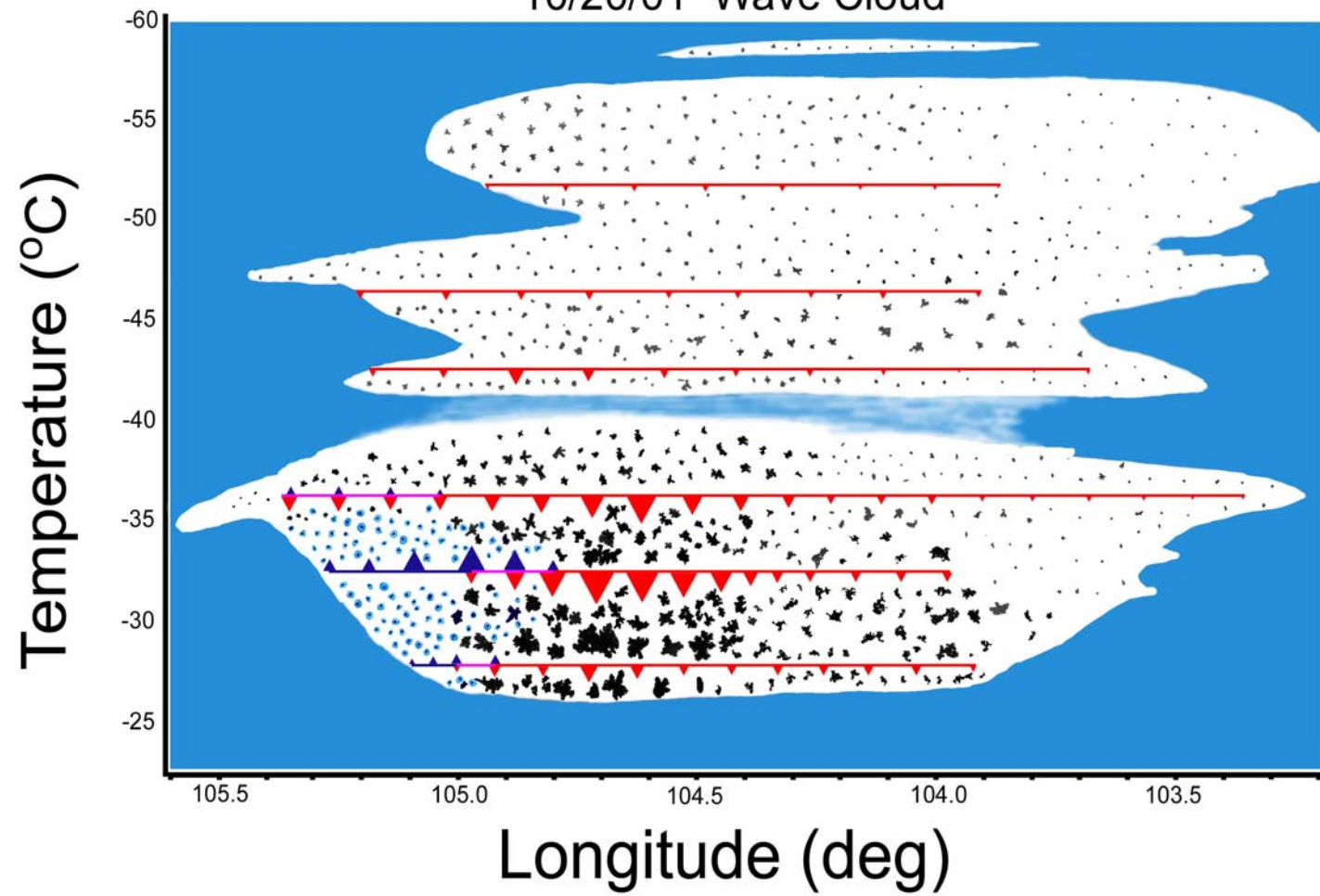
$P = \text{Perimeter}$



Wave Cloud Investigated by the SPEC Learjet



10/20/01 Wave Cloud



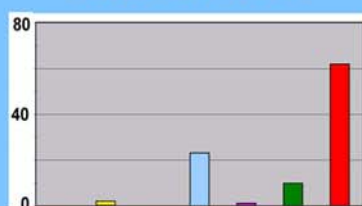
VERTICAL PROFILE OF CRYSTAL HABITS FOR 75 WAVE PASSES IN 11 CLOUDS ($\sim 10^5$ particles)

Wave Cloud Habits % by Mass

11 Flights
75 Regional Legs
88,390 Total Particles

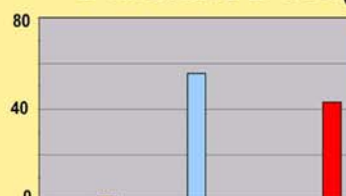
Wind →

Mixed Phase

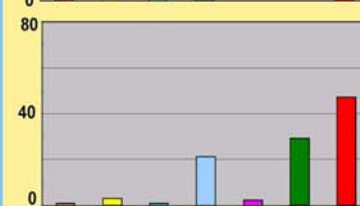
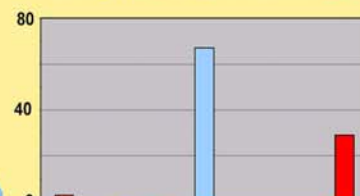
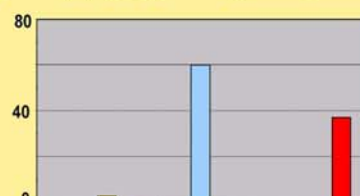


COLUMNS
SMALL IRREGULARS
AGGREGATES
ROSETTES

Glaciated Region

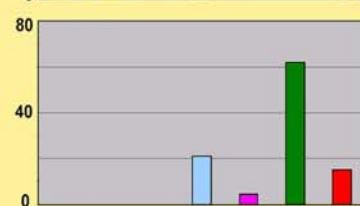
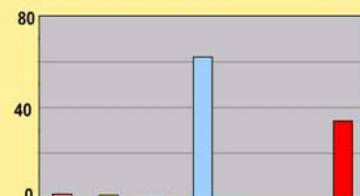
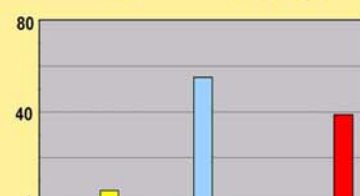


West



COLUMNS
SMALL IRREGULARS
AGGREGATES
ROSETTES

East



COLUMNS
SMALL IRREGULARS
AGGREGATES
ROSETTES

-55 C

-45 C

-35 C

-30 C

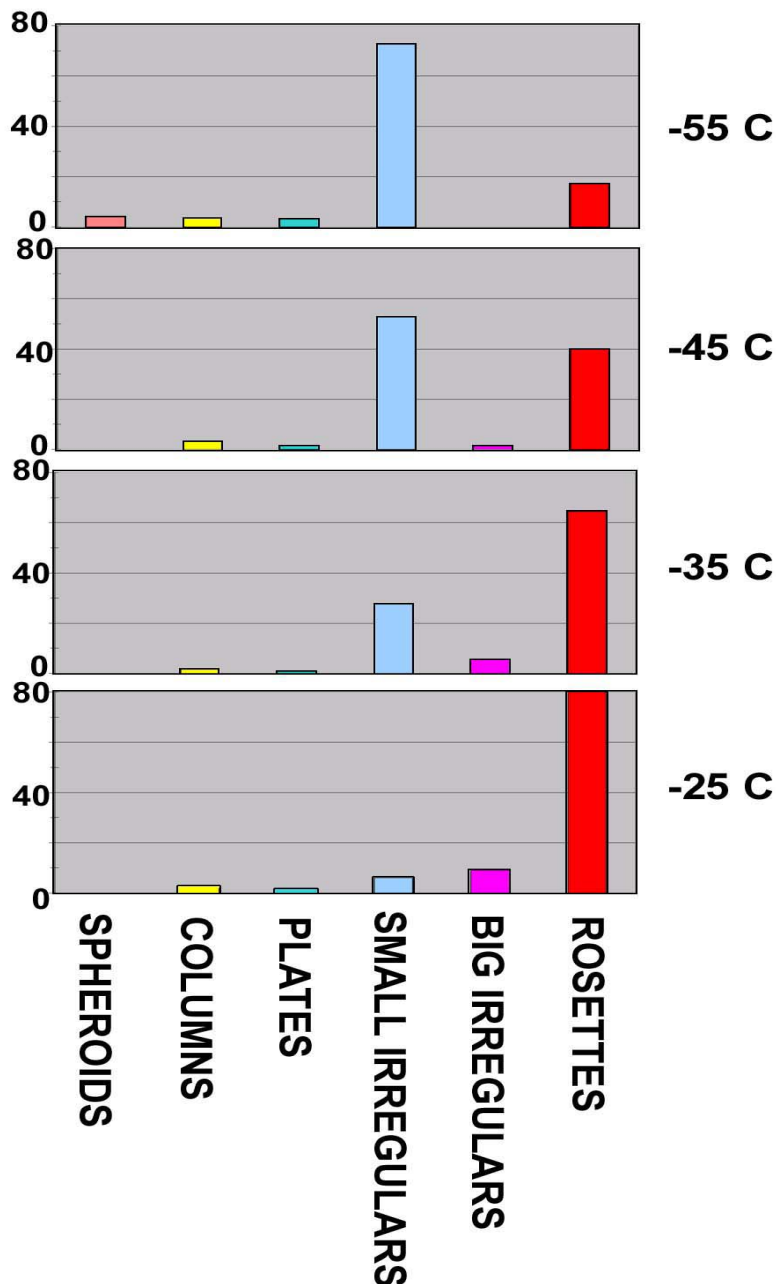
-25 C

CIRRUS CLOUDS

VERTICAL PROFILE OF CRYSTAL HABITS
FOR 66 PASSES IN 13 MID-LATITUDE
CLOUDS (> 250,000 particles)

Cirrus Cloud Habits % by Mass

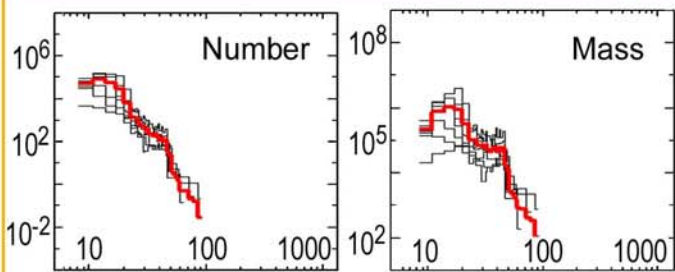
13 Flights
66 Extended Legs
256,559 Total Particles



WAVE vs CIRRUS

Wave Clouds (Glaciated Region)

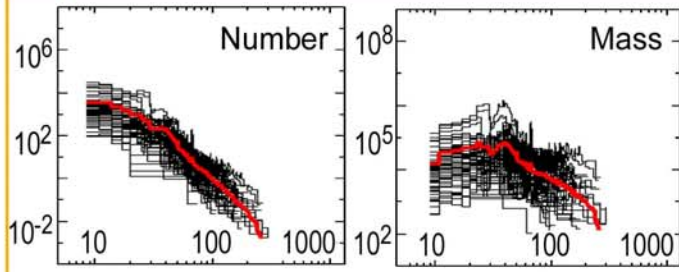
-55 C



Conc= 10,270 L⁻¹ $r_{\text{eff}} = 8.40 \mu\text{m}$
IWC= 0.016 g m⁻³ $\beta_{\text{ext}} = 2.45 \text{ Km}^{-1}$

43% Rosettes

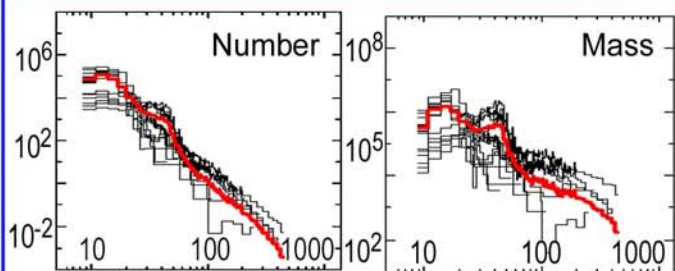
Cirrus Clouds



Conc= 640 L⁻¹ $R_{\text{eff}} = 18.4 \mu\text{m}$
IWC= 0.003 g m⁻³ $\beta_{\text{ext}} = 0.25 \text{ Km}^{-1}$

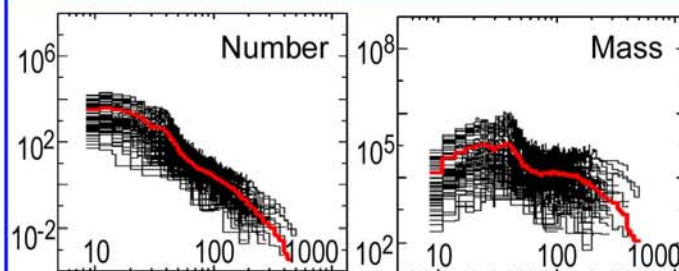
18% Rosettes

-45 C



Conc= 14,005 L⁻¹ $r_{\text{eff}} = 12.6 \mu\text{m}$
IWC= 0.023 g m⁻³ $\beta_{\text{ext}} = 3.41 \text{ Km}^{-1}$

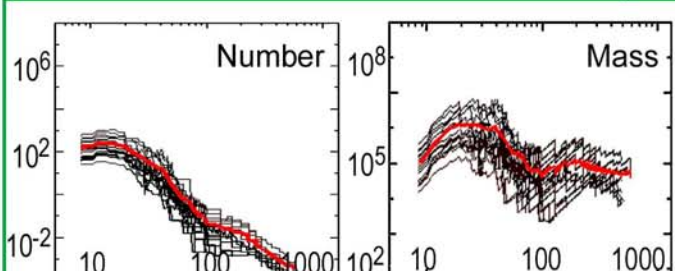
37% Rosettes



Conc= 755 L⁻¹ $r_{\text{eff}} = 25.0 \mu\text{m}$
IWC= 0.006 g m⁻³ $\beta_{\text{ext}} = 0.76 \text{ Km}^{-1}$

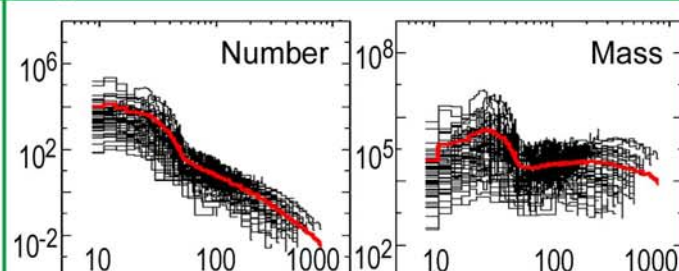
40% Rosettes

-35 C



Conc= 6,050 L⁻¹ $r_{\text{eff}} = 18.2 \mu\text{m}$
IWC= 0.030 g m⁻³ $\beta_{\text{ext}} = 3.17 \text{ Km}^{-1}$

30% Rosettes

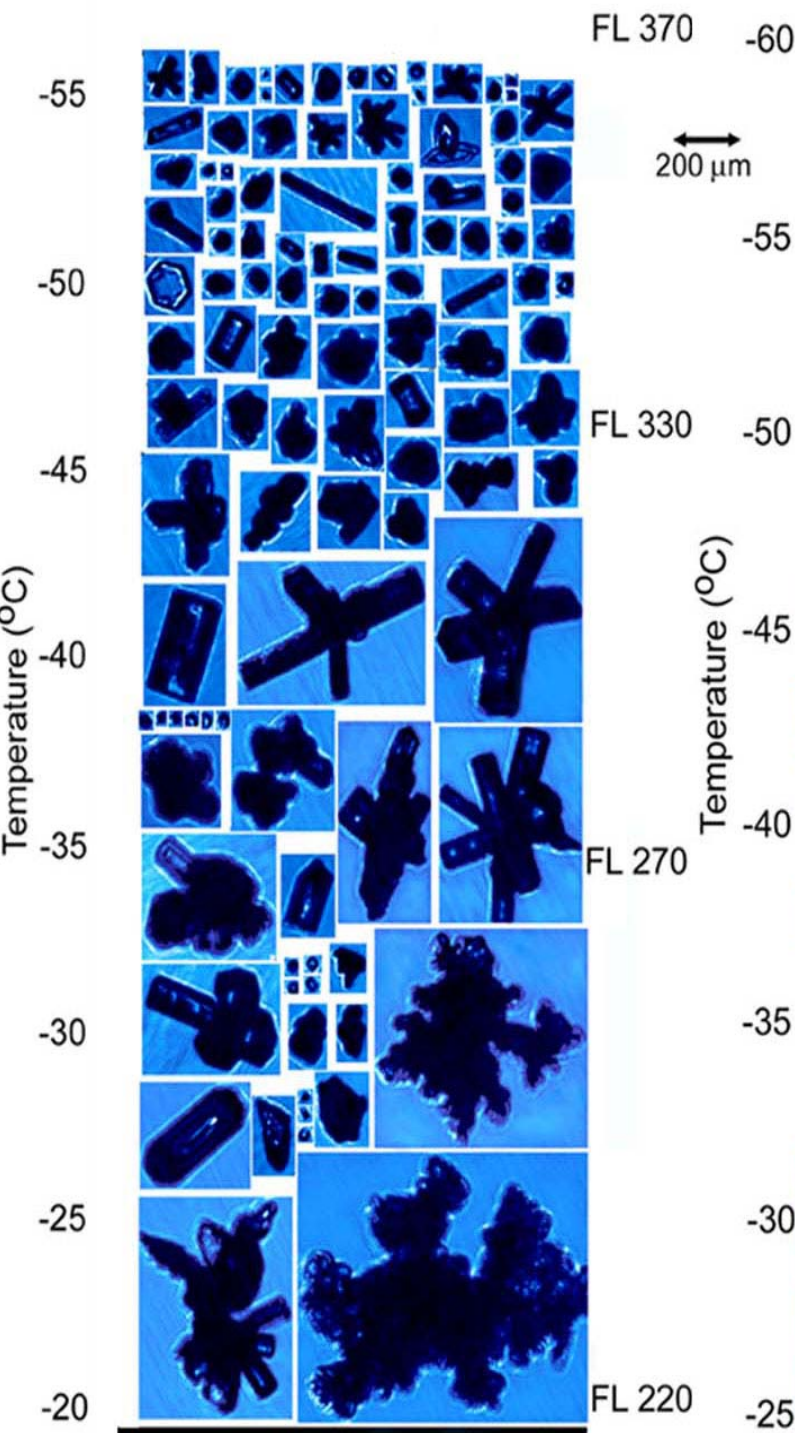


Conc= 3,200 L⁻¹ $r_{\text{eff}} = 36.7 \mu\text{m}$
IWC= 0.022 g m⁻³ $\beta_{\text{ext}} = 0.83 \text{ Km}^{-1}$

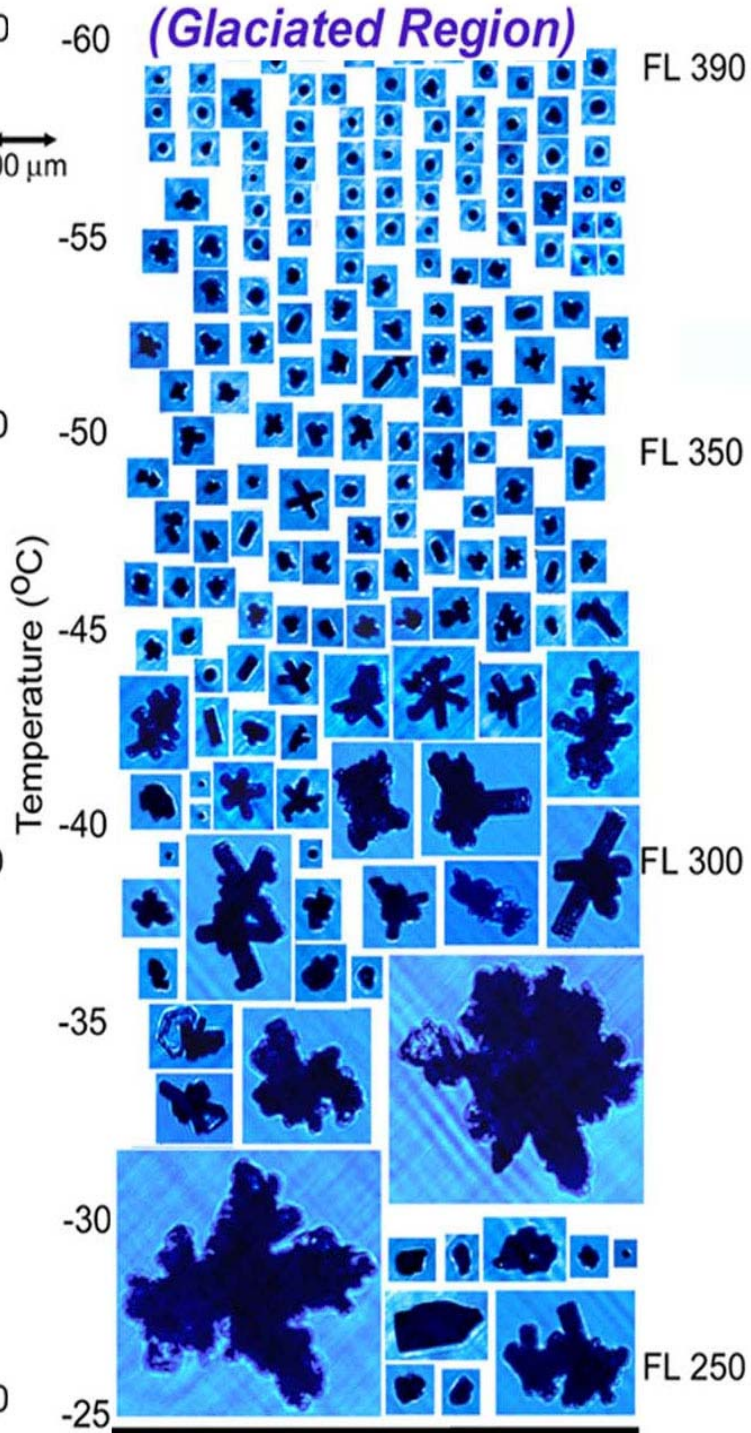
63% Rosettes

THICK CIRRUS VS WAVE CLOUD

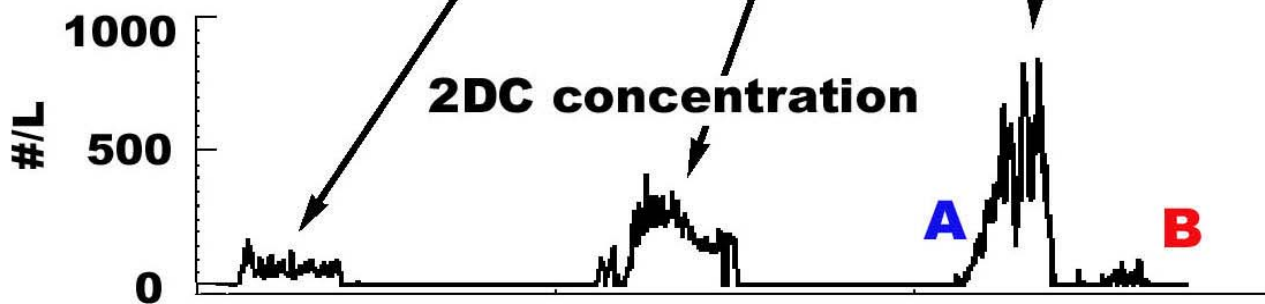
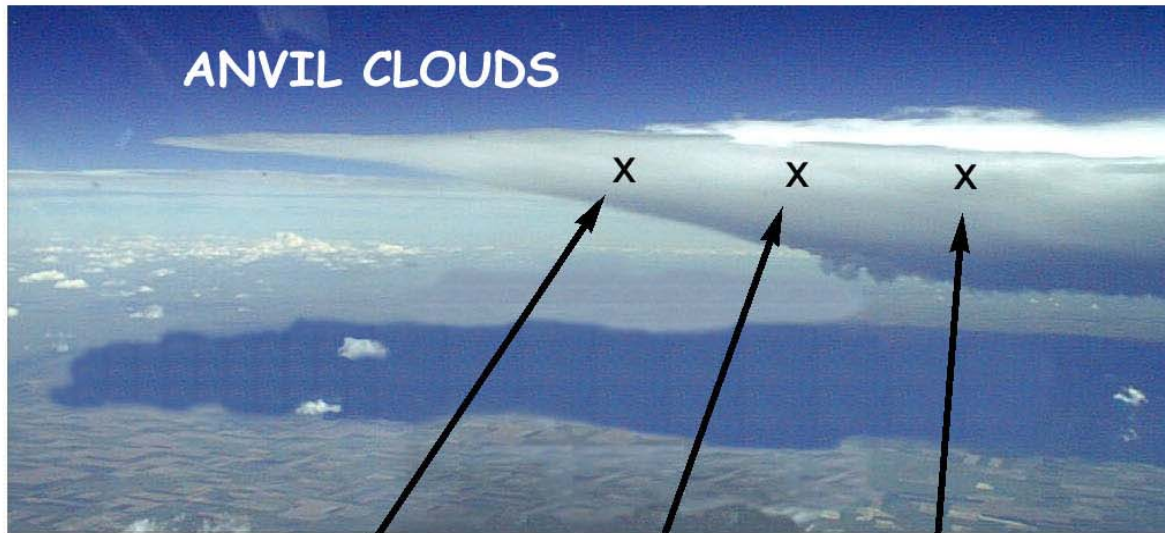
THICK CIRRUS



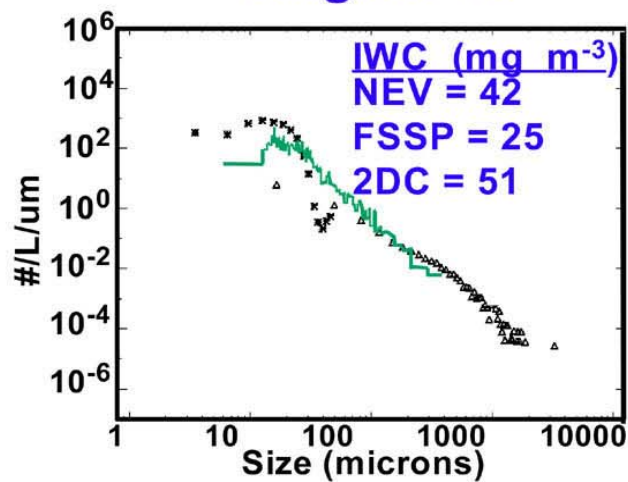
WAVE CLOUD (Glaciated Region)



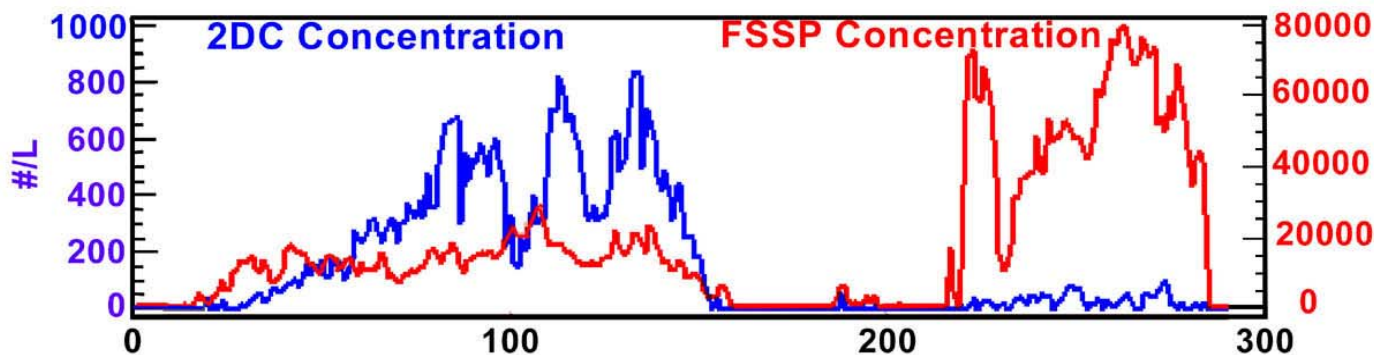
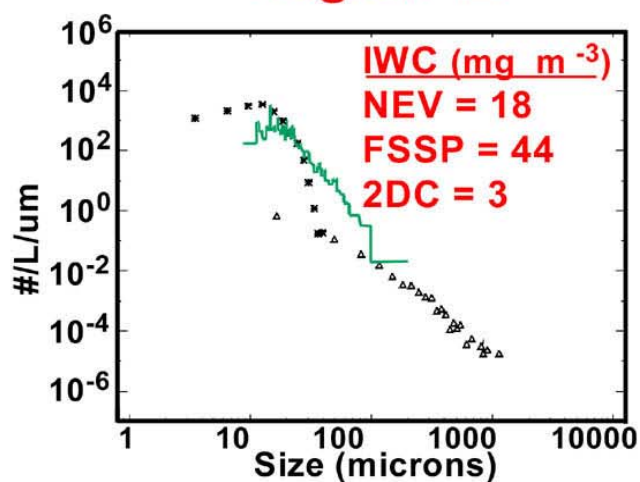
ANVIL CLOUDS



Region A

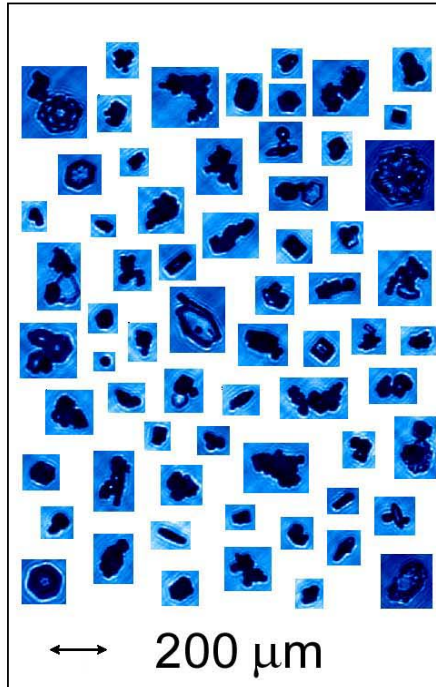
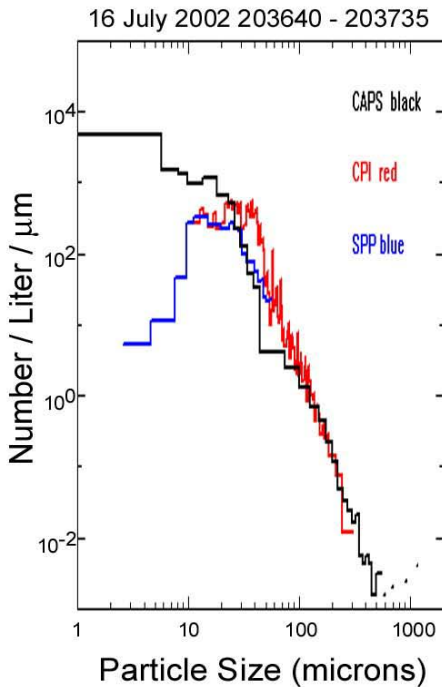


Region B



16 July C-F Anvil Mission

WB-57 FL = 460 T = -65°C



Computed From
(SPP-CPI-CIP) PSD:

$$\text{CONC} = 7,700 \text{ L}^{-1}$$

$$\text{IWC} = 0.13 \text{ gm}^{-3}$$

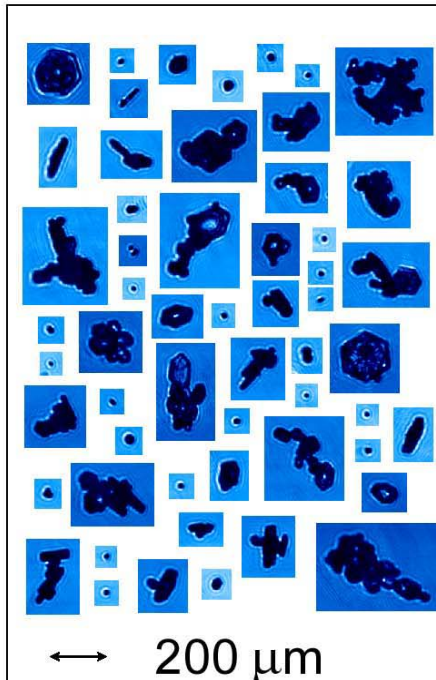
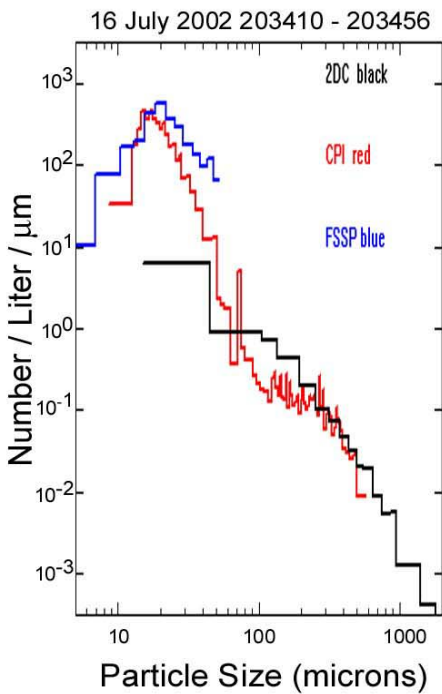
$$\beta_{\text{ext}} = 9 \text{ Km}^{-1}$$

$$r_{\text{eff}} = 20 \mu\text{m}$$

$$\text{IWC (Harv.)} = 0.16 \text{ gm}^{-3}$$

$$\text{IWC (CU)} = \text{N/A}$$

$$\beta_{\text{ext}} (\text{CIN}) = \text{N/A}$$



Computed From
CPI PSD:

$$\text{CONC} = 9,600 \text{ L}^{-1}$$

$$\text{IWC} = 0.25 \text{ gm}^{-3}$$

$$\beta_{\text{ext}} = 47 \text{ Km}^{-1}$$

$$r_{\text{eff}} = 32 \mu\text{m}$$

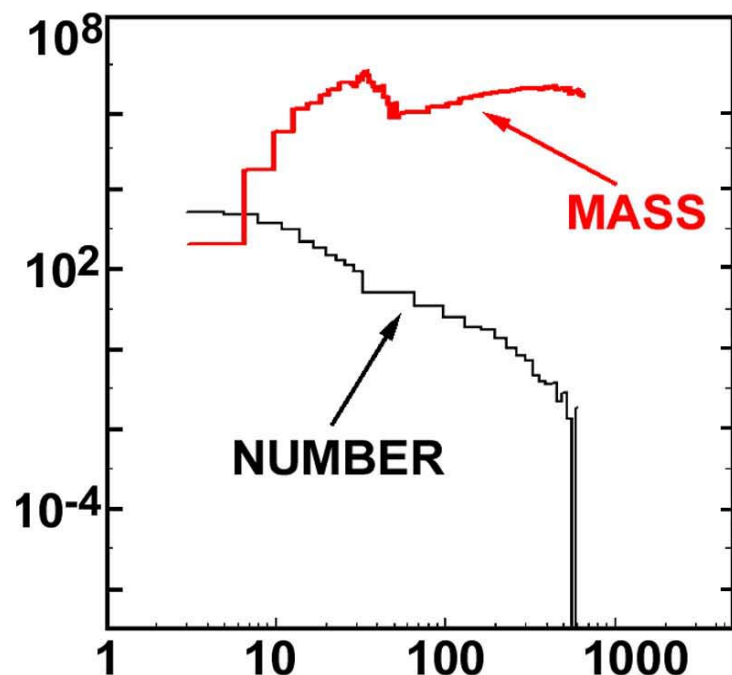
$$\text{IWC (CIN)} = 0.28 \text{ gm}^{-3}$$

$$\beta_{\text{ext}} (\text{CIN}) = 37 \text{ Km}^{-1}$$

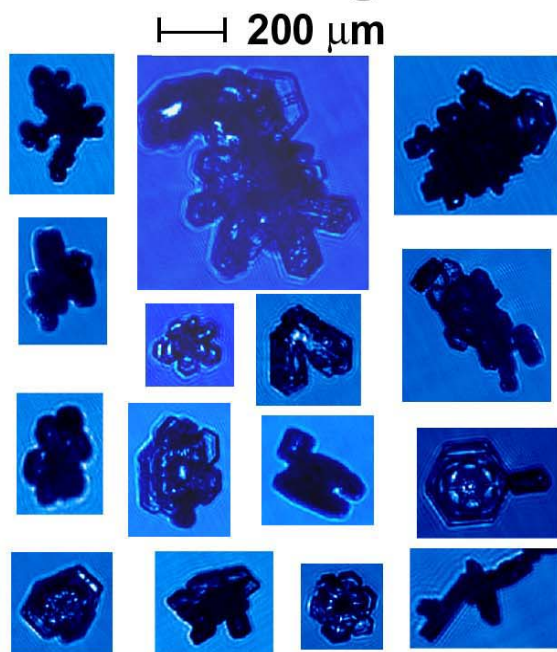
$$r_{\text{eff}} (\text{CIN+CVI}) = 12 \mu\text{m}$$

13-JUN-00 Anvil: 21:29:30 - 21:29:40

Composite FSSP & 2D-C Particle Size Distribution



CPI Images



Computed from Composite PSD

$$\text{IWC} = 0.57 \text{ g m}^{-3}$$

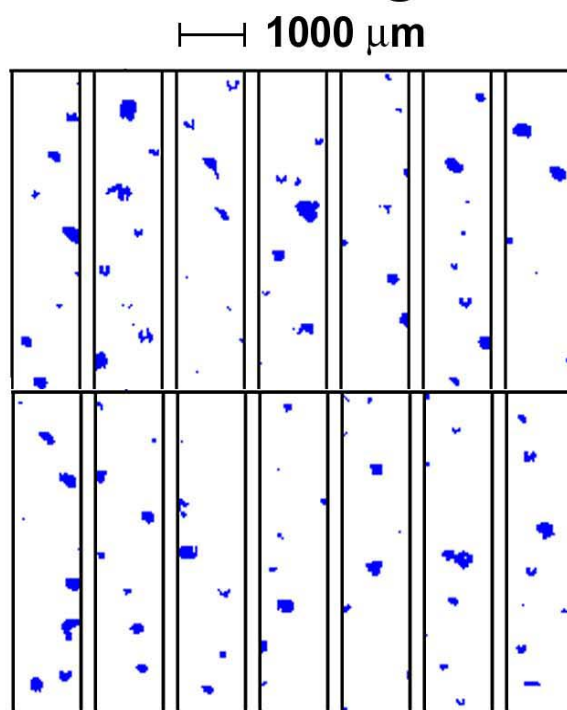
$$\text{Total Conc} = 24,000 \text{ L}^{-1}$$

$$\text{2D-C Conc} = 4,000 \text{ L}^{-1}$$

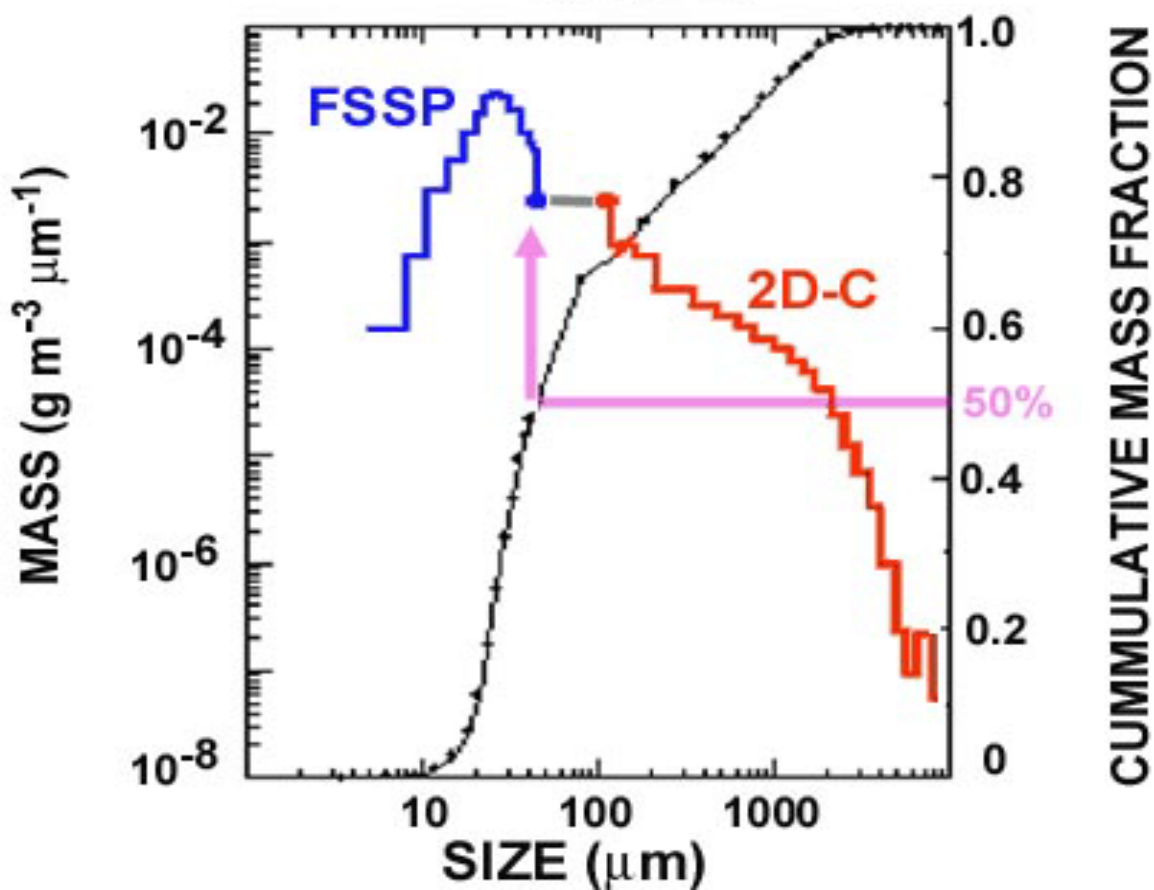
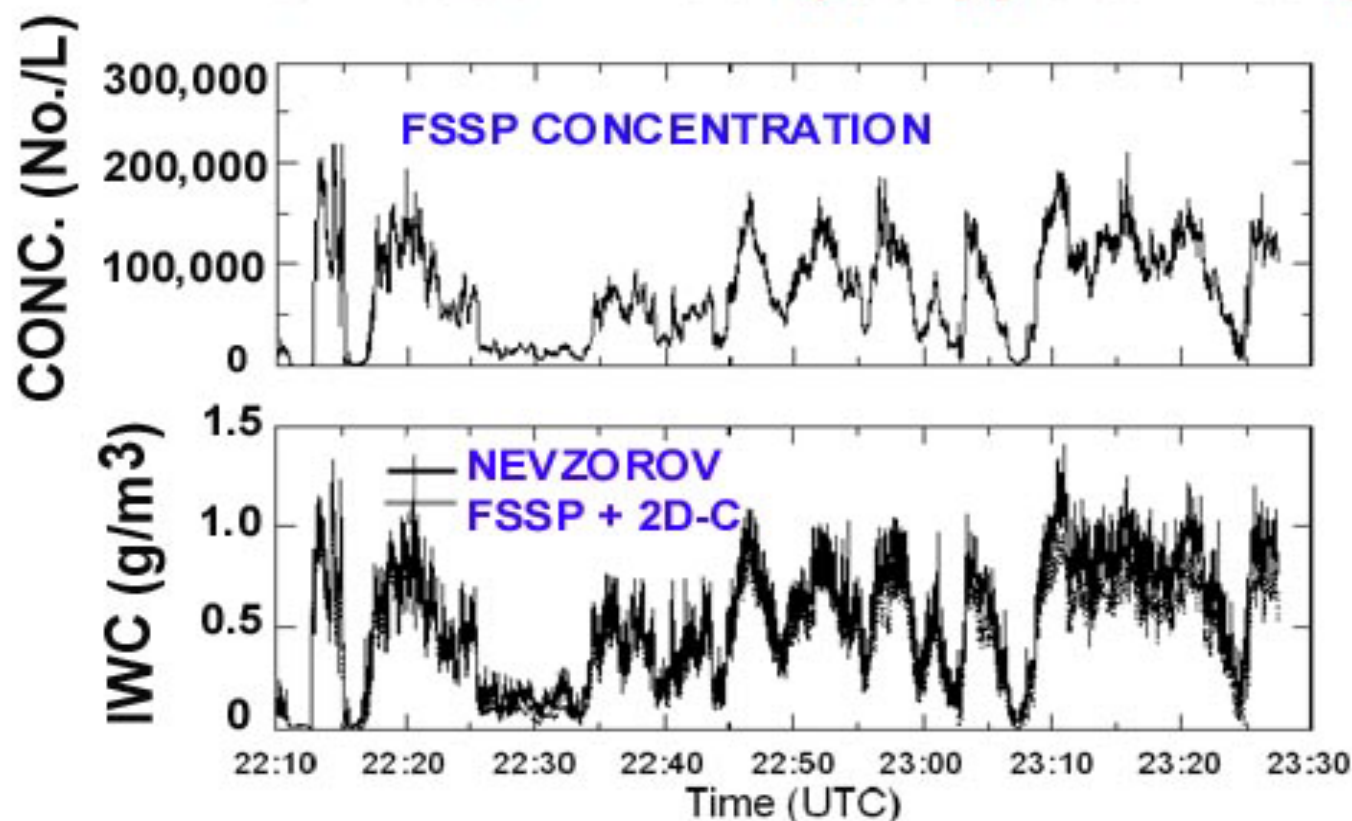
$$\beta_{\text{ext}} = 43 \text{ Km}^{-1}$$

$$r_{\text{eff}} = 98 \text{ μm}$$

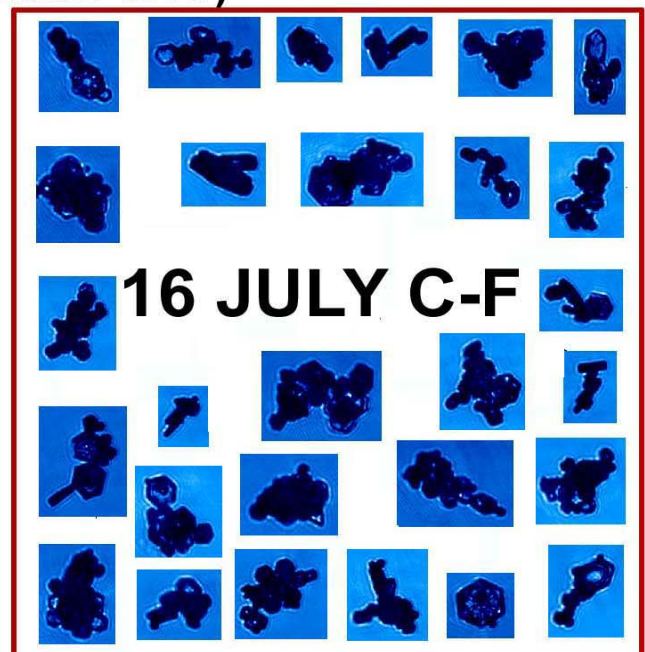
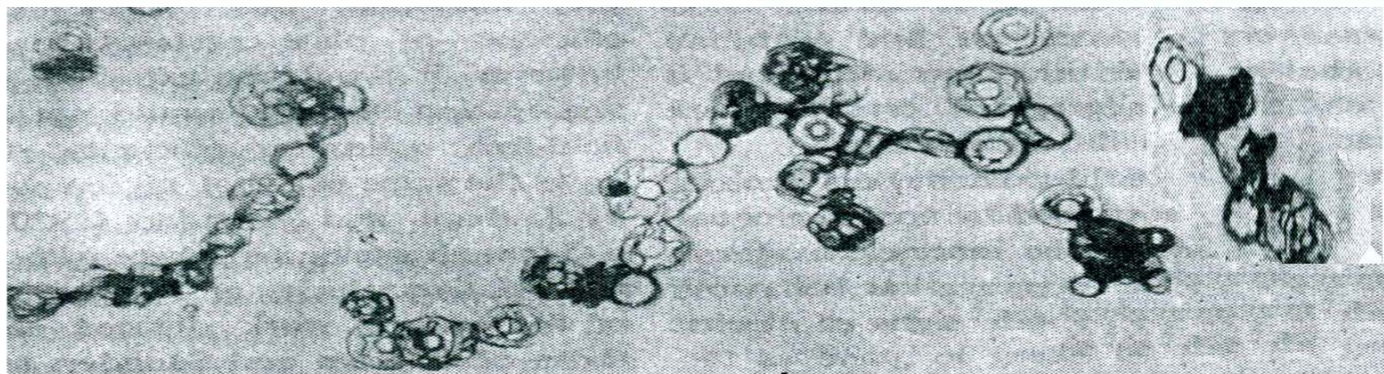
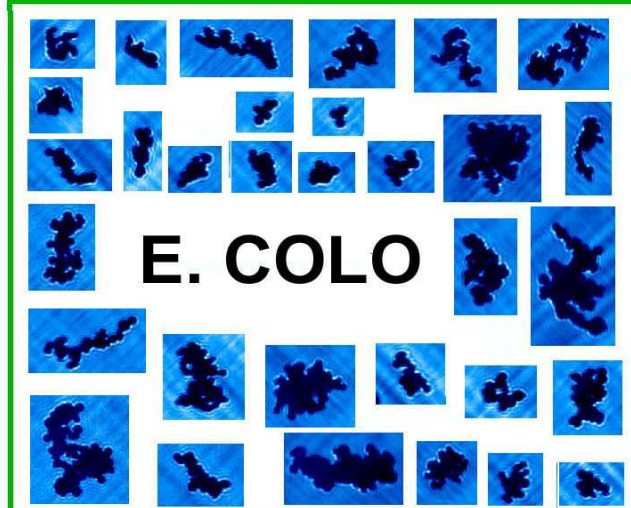
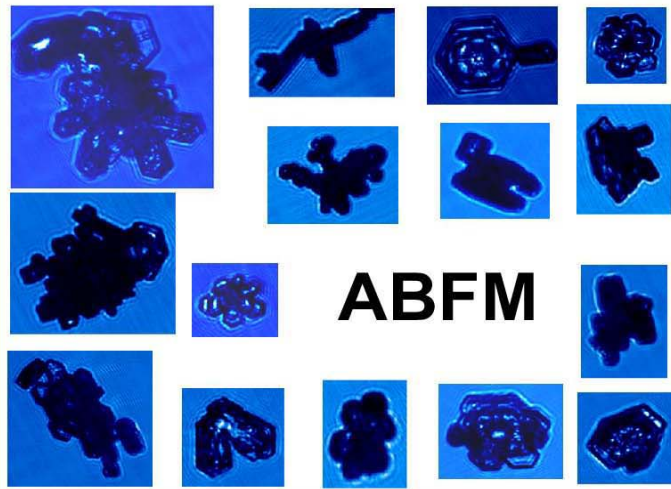
2D-C Images



ALLIED/BAE FLIGHT IN ARKANSAS ANVIL ON 16 JUNE 1997 (Strapp et al. 1999)



Examples of Likely Influence of E-Field on Aggregation



MAJOR FINDINGS

• WAVE CLOUDS:

- Ice Particle Concentrations: $1 - 20 \text{ cm}^{-3}$ (Typ.)
- Bullet Rosettes dominate particle habits from about -25 to about -45 C . Small spheroidal particles and budding rosettes found from -45 to -55 C .
- Highest IWC found just downwind of region with supercooled water ($T > -37 \text{ C}$)
- Riming, sideplane growth and (lastly) aggregation found downwind of region with supercooled water.
- β_{ext} values from about 1 to 10 (in SLW), r_{eff} from about 5 to 30, $\text{IWC} < 0.2 \text{ g m}^{-3}$

• CIRRUS CLOUDS:

- Ice Particle Concentrations: $0.1 - 5 \text{ cm}^{-3}$ (Typ.)
- Bullet Rosettes dominate particle habits from about -25 to about -45 C . Small spheroidal particles and budding rosettes found from -45 to -55 C .
- PSDs similar to downwind part of wave cloud
- Aggregates of Bullet Rosettes found in moderately deep cirrus. Sideplane growth and riming found in some deep cirrus
- β_{ext} values from 0.1 to 1 Km^{-1} , r_{eff} from 10 to 50, $\text{IWC} < 0.05 \text{ g m}^{-3}$

MAJOR FINDINGS

(Continued)

- **ANVIL CLOUDS:**

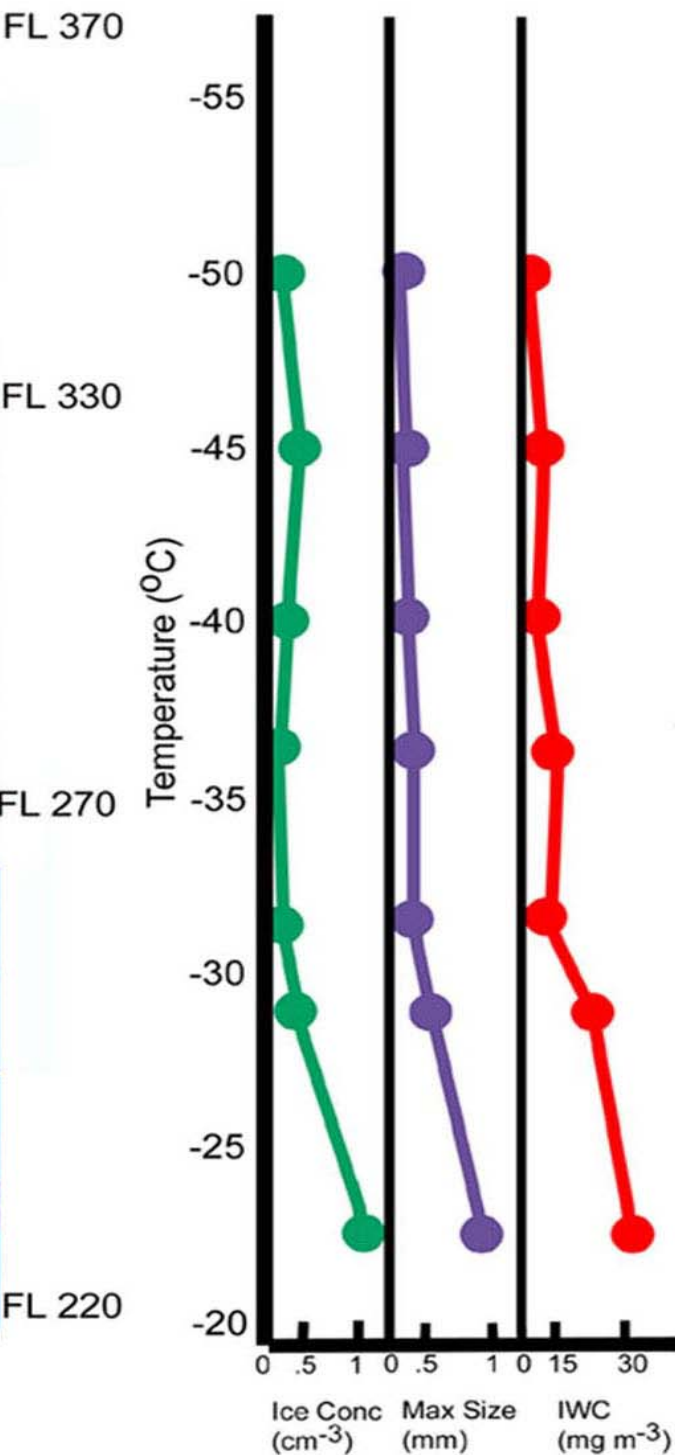
- Ice Particle Concentrations: 1 to $> 100 \text{ cm}^{-3}$ (Typ.)
- Particle habits mainly irregular shapes, aggregates, plates and some columns (virtually no bullet rosettes)
- Aggregates occasionally observed in “Chains”, which are likely formed as a result of high electric fields.
- β_{ext} values from 1 to 50, r_{eff} from 10 to $100 \text{ }\mu\text{m}$, IWC 0.1 to $> 1 \text{ g m}^{-3}$
- Particle Concentration, IWC, β_{ext} , r_{eff} all decrease with distance from center of convection and increasing altitude.

NEXT STEPS...

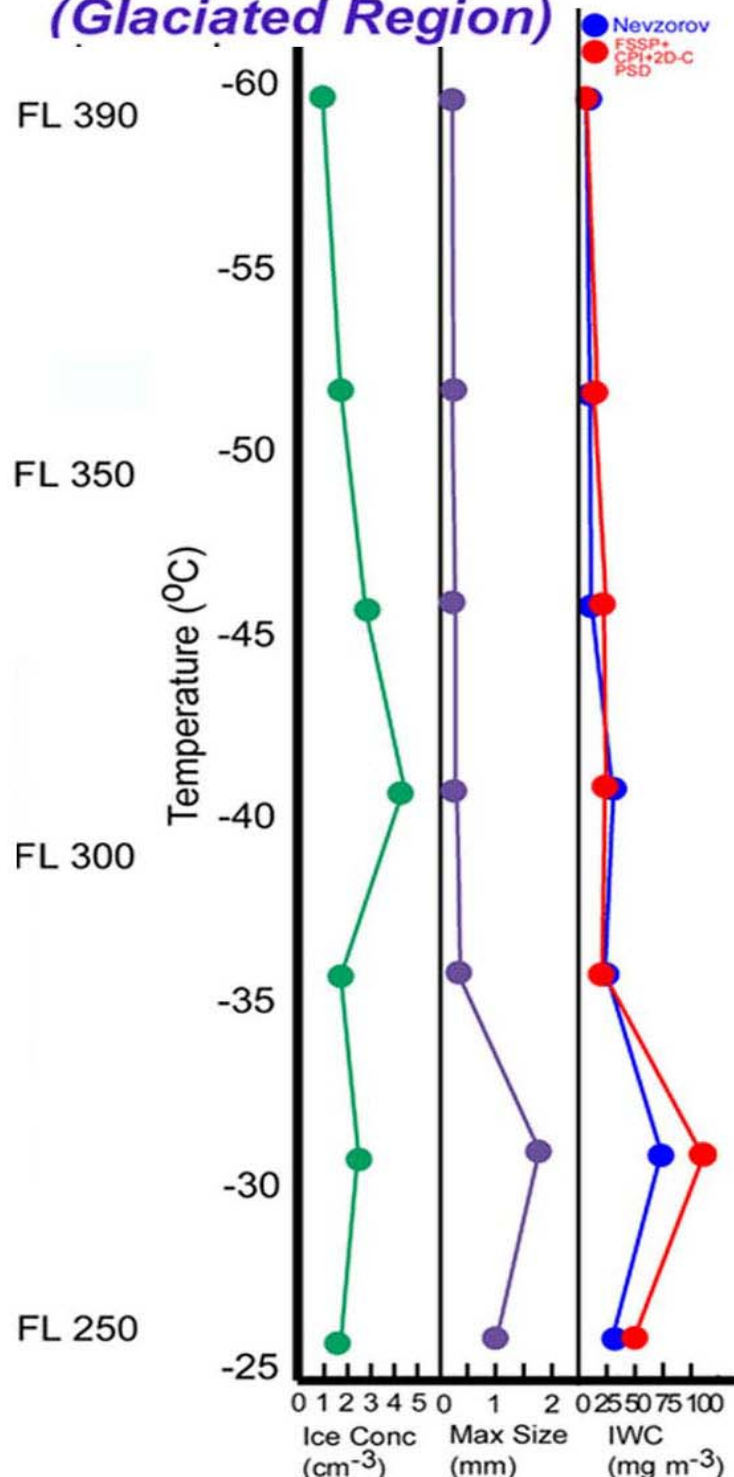
- Piece together relative location of storm from radar, satellite and video relative to WB-57 and Citation flight tracks
- Construct vertical and horizontal profiles of anvil microphysics from WB-57 and Citation measurements
- Construct, if possible, quasi-3D pictures of the storm/anvil profile with microphysical properties.
- Compare microphysical properties with remote measurements.

THICK CIRRUS VS WAVE CLOUD

THICK CIRRUS



WAVE CLOUD (Glaciated Region)



Volume 82

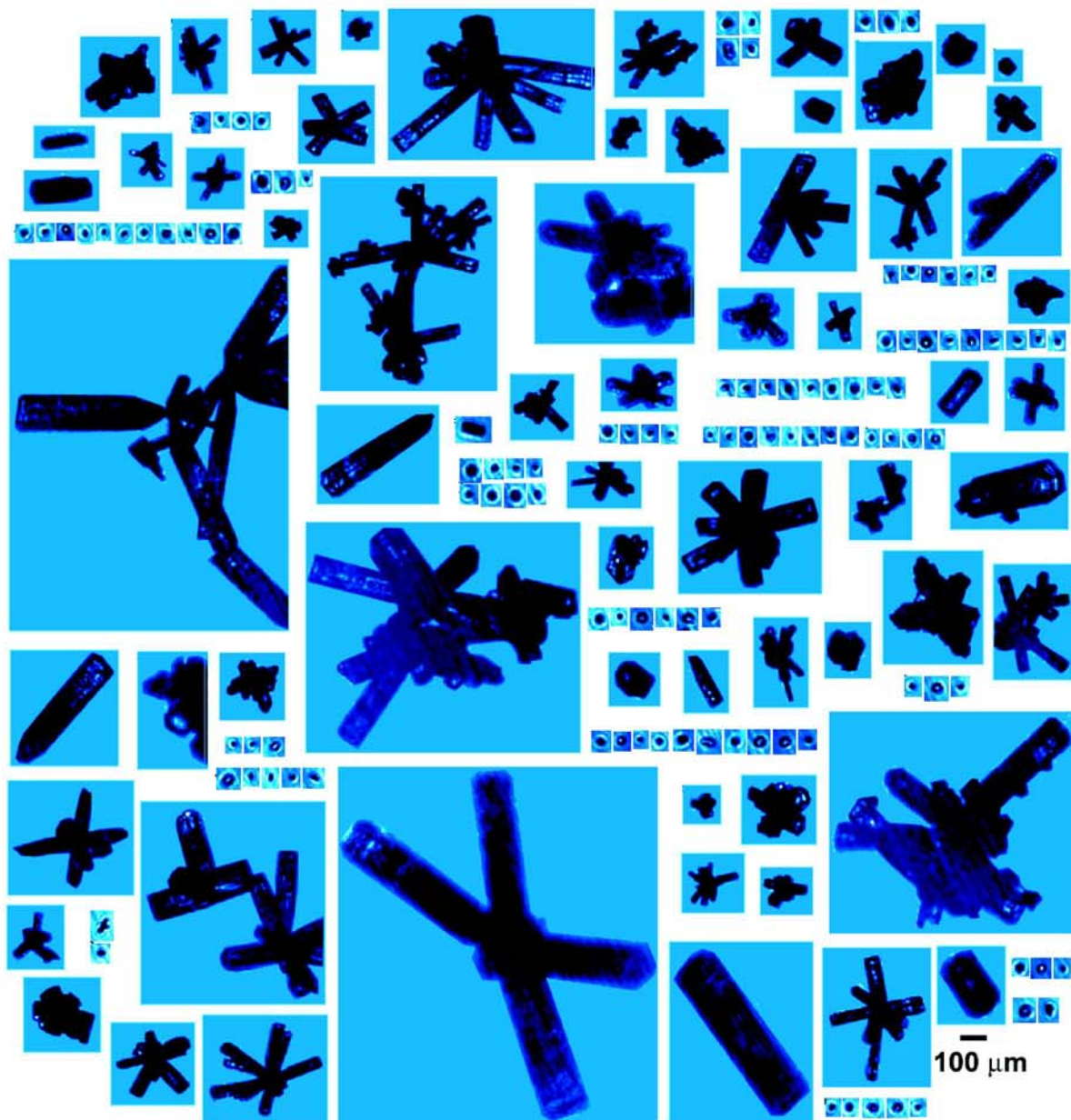
Number 6

June 2001

bulletin

of the
American Meteorological Society

CPI Images of Cirrus Ice Crystals



Data Collected on 1 June 1999 over the Facility
for Atmospheric Remote Sensing in Utah